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CONCEPTS AND TECHNIQUES
FOR SUMMARIZING DEFENSE
SYSTEM COSTS

By J. W. Noah

SYSTEMS EVALUATION GROUP

RESEARCH CONTRIBUTION NO. 1

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ABSTRACT

Some techniques used to summarize total costs employed in systems analyses are classified, described, and compared. Their respective advantages and disadvantages are given, and some implications of each are brought out.

Five cost-summarizing techniques are selected and distinctions between them are based on common usage. The procedures are termed:

- Five-Year System Cost
- Period Outlay
- Net Cost
- Present Cost
- Annual Cost

Necessary to their discussion is an understanding of the major types and general content of defense system cost analyses, the concept of remaining value, and the principle that money has time value. A brief section on each of these subjects with appropriate references precedes the discussion of the methods for summarizing costs.

PREFACE

Studies conducted by the Naval Warfare Analysis Group of the Center for Naval Analyses during the past two years have encountered numerous problems relating to the selection of cost analysis practices that permit appropriate comparisons among systems. Some of the issues involved include the selection of an appropriate time horizon, the treatment of remaining values and/or unequal lifetimes of systems, the treatment of time preference, the influence of build-up costs associated with the phase-in period of a new system, etc. This document directs its attention to some of the main issues involved in the selection of an appropriate cost summarizing technique.

For criticisms and helpful suggestions, and for clarifying some vague points and rewriting others, I am indebted to N.V. Breckner, V.L. Broussalian and R.P. Caldarone of CNA. Special thanks go to Erwin Baumgarten and W.D. Weir, both of CNA, who have been instrumental in formulating the "period outlay" summarization as defined here. I would also like to thank Harry P. Hatry of the OSD (Comptroller) Programming Office, and R.N. Grosse, E.B. Berman, B. Sobin and John Surmeier of the Research Analysis Corporation for their intensive review and useful comments. Unfortunately, I cannot claim that any of those who have been kind enough to help me in this endeavor are in full agreement with the product. Its faults are mine alone.

I am also grateful to the students enrolled in the Cost Analysis and Systems Analysis courses (Spring 1965) at the USN Postgraduate School, Monterey, California, for their attention and comments. It is hoped this material will be useful to future defense management courses.

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SUMMARY

Essentially there are three major types of cost analyses finding use in the Defense Department. They include individual weapon system analysis, mission force structure analysis and total force structure analysis. These types differ not only in content, but usually in the level of detail sought for individual cost elements and estimating relationships. The kind of summary technique selected depends to some extent upon the type of cost analysis being conducted.

Costs of a military defense system typically divide between research and development, initial investment, and annual operations. Or, in some cases, the division may more appropriately be thought of in terms of non-recurring and recurring costs. Briefly, the categories are as follows:

Non-Recurring

Research and Development: includes the cost of all activities and test hardware necessary to demonstrate the operational feasibility of a defense system.

Initial Investment: includes the cost of producing and constructing all hardware and facilities, training and locating personnel necessary to introduce a new system into the operational force.

Recurring

Operations: includes all those annual outlays needed to maintain a defense system in an operationally-ready state.

The above categorization has been termed "cradle-to-grave"; that is, all costs are included from conception of the idea for a system to its phase-out of the operational force. Naval systems typically have a long useful lifetime relative to land and air defense systems, and occasionally the study period is cut off short of the estimated lifetime, or the "grave". Some consideration must usually be given to the value of the system remaining beyond the time horizon selected for study.

Estimates of remaining values of military defense systems pose many problems unique to non-marketable assets. Reliance upon methods of depreciation accounting is conceptually incorrect, although such methods are sometimes sponsored as useful means for quantifying highly-uncertain values. A listing of the age of assets at the end of the study period may in some cases render more complete and judicious information to the decision maker.

Because resources have a capacity to earn a net return in alternative uses, and because of the existence of interest, or money paid for the use of borrowed money, the prospect of having to spend a dollar five years from now is less severe than the prospect of having to spend one in the immediate future. Expected future cost streams which differ in total magnitude may very well be

equivalent when the time value of money is taken into account. Techniques of financial mathematics are designed to aid in the calculation of equivalent cost streams, and the operation of reducing cost streams to their present values is popularly called discounting. Alternative investment proposals should usually be examined for sensitivity to time preference, or time value.

Five separate methods for summarizing total system costs discussed in this document are: 5-year system cost, net cost, period outlay, present cost, and annual cost. As popularly employed, the first 3 do not incorporate discounting as an integral part of the method; the last 2 do. However, all 5 techniques are amenable to the application of discounting. Briefly, characteristics of each summary technique, as employed in this discussion, are as follows:

Five-Year System Cost: This technique arithmetically sums the R&D, initial investment and 5 times the annual cost of operating the system at a specified force level. Value of assets remaining at the end of 5 years are not treated in the cost analysis; the time value of money is not considered; build-up costs* are included (see page 25).

Period Outlay: This approach is similar to the 5-year systems cost in that neither treat time value; it differs in that build-up or phase-in costs are included, costs are time-phased, and remaining value is treated by listing the age of assets as of the study cut-off date (see page 27).

Net Cost: The main distinguishing feature of the net cost technique is that remaining values are treated quantitatively, and estimates of unequal useful lifetimes of alternatives are thus recognized (see page 28).

Present Cost: This technique summarizes costs in terms of their present value; cost streams are estimated over a period sufficiently long to encompass the least common multiple of the lives of alternatives. In this way, the need to estimate remaining values during the lifetime of any one of the alternatives is avoided (see page 29).

Annual Cost: All of the features of the present cost technique are incorporated in the annual cost; the present cost is merely reduced to an equivalent uniform annual cost (see page 31).

All of the above techniques employ the constant dollar as the unit of measure; i.e., the influence of price level changes is neglected (see page 25). The following matrix lists the characteristics:

*Build-up costs are operating costs incurred during the phase-in period; i.e., before the new system reaches its full force size.

CHARACTERISTICS OF SUMMARIZING TECHNIQUES

	5-Year Cost	Period Outlay	Net Cost	Present Cost	Annual Cost
1. Time-phased costs	N	Y	Y	Y	Y
2. Recognizes unequal lifetimes	N	N	Y	Y	Y
3. Includes build-up costs	N	Y	Y	Y	Y
4. Recognizes time value of money	N	N	N	Y	Y
5. Employs constant dollar	Y	Y	Y	Y	Y

Note: Y = Yes; N = No

As an aid to exposition, I have elected to spell out several techniques for summarizing defense system costs. Each of the techniques discussed is purposely defined explicitly and narrowly to aid subsequent comparisons. Various combinations of the above characteristics could describe or define other techniques for summarizing total system costs.

For purposes of comparing selected summary techniques, I have taken present* cost as my standard because it is sensitive to all characteristics addressed: unequal lifetimes, build-up costs, and time value of money. For specified sets of cost streams, total system costs are summarized by each of the other summary methods. The rate of interest necessary in the present cost calculation to yield the same total system cost as found by another method is determined. That rate is referred to as the implied interest or discount rate.

The implications of selecting the 5-year system cost or period outlay technique as an appropriate summary device vary quite widely depending upon the shape of the expected cash flow pattern. On the basis of several hypothetical examples, implied interest rates vary from about 5 to 18 percent for systems expected to have a useful life of 10 years, and from 7 to 23 percent for those lasting 20 years.

Implications of selecting one of the net cost techniques also vary depending upon the shape of cost streams. In some examples, net cost may be approximated by present cost using interest rates on the order of 40 to 50 percent. There are other examples in which the net cost implies an infinite rate of interest, and still others whose net costs <u>cannot</u> be approximated by the use of present cost. The latter are <u>not</u> exceptional or out-of-the-ordinary examples as one might suspect.

The cash flow pattern represented by the development, procurement and operation of a hypothetical major weapon system is given on pages 35 and 36. Initial investment funds are expended over a period of seven years overlapping the last three years of development effort, and the annual operating costs begin

*Or equivalent uniform annual cost.

with the phase-in of the first operational system in the sixth year after initiation of systems development. Rates of interest implied by that example for each summarizing technique are as follows:

DISCOUNT RATE IMPLICATIONS
(Of hypothetical case, page 35)

Expected Useful Life, Years	5	10	20
1. Five-year systems cost	0%	5%	7%
2. Period outlay, 5 years	0%	3%	5%
3. Net cost, 5 years			
Straight line	0%	5%	7%
Double declining balance	0+%	4%	8%
Sum-of-years digits	0%	4%	8%
Sinking fund	0%	6%	10%

There has, I believe, been an overemphasis on the use of the 5-year system cost technique in the past. Because of the simplifications associated with that technique, I think such overemphasis is unfortunate. This is not meant to suggest that the 5-year cost has no place in defense system cost analysis. On the contrary, the simplifications associated with the 5-year system cost technique are probably not crucial in an analysis of advanced systems whose conceptual designs rely upon technological advances predicted to be made sometime in the next decade or so. Systems such as the aerospace plane, or the nuclear powered low-altitude missile, or the long-endurance electrical propulsion system suitable for interplanetary travel, etc., impose requirements and costs that cannot usually be estimated with accuracy sufficient to warrant paying undue attention to time value, remaining value, etc.

For systems less advanced in concept, whose specifications can be estimated with more accuracy, and whose costs in quantity procurement are large, there is a need to consider the influence of unequal lifetimes of alternatives, time value, build-up costs, etc. Also, there is a need to make our analysis of resource costs more dynamic; that is, feasible production and construction schedules should be examined more carefully, and their economic impact in terms of time-phased costs should be an integral part of a systems analysis. More attention should be paid to the question, "Are we examining systems having a useful capability over the same time period?" In short, we should concentrate more effort on the time distribution of both effectiveness and resource cost; continued reliance on the static approach (like the 5-year systems cost) and the examination of measures of effectiveness at one future date will tend to confuse the issues involved in and the aims of a good systems analysis.

In general, I believe one should think in terms of approaching the cost analysis task using the present cost technique, and if special considerations deem that impractical then progress back through net cost, then period outlay and on to the 5-year system cost technique for the kind of situation described above.

Perhaps the most important characteristics of the present cost technique as defined here is that it requires the use of a time period equal to the lowest common multiple of the estimated useful lifetimes of the major assets involved in the systems being compared.

MAJOR TYPES AND GENERAL CONTENT OF COST ANALYSES

Fisher classifies cost analyses into two major types (reference (a)):

"(1) Individual weapon/support system cost analysis: the determination of the probable economic resource impact of alternative future system proposals.

(2) Total force structure cost analysis: the determination of the probable economic resource impact of alternative future total force proposals (aggregations of systems and non-system oriented activities)."

He points out that there are variations which are in effect sub-sets of (1) and (2) above. He says, "there may be instances where only a sub-set of a projected total Air Force is of interest: the strategic retaliatory mission, or the limited war forces." The major share of studies conducted at CNA involve mission areas which include a number of systems but fall short of including the entire Navy. From the viewpoint of CNA, there is then a need to focus attention on a third major type of cost analysis, and it is one that falls between the two defined above:

Mission force structure cost analysis: the determination of the probable economic resource impact of alternative forces proposed to accomplish a given mission (aggregations of systems and support activities relevant to the given mission).

There are of course many interdependencies between these three major types. For example, the total Navy is made up of many individual weapon and non-weapon systems supported by activities which are entirely non-system oriented. Nevertheless, the level of detail sought for individual systems is usually greater than that for the total force structure. Occasionally it is necessary to a comparison of individual weapons to be sensitive to design details which become unimportant (or at least unmanageable) in the aggregation of a number of weapon systems.

The selection of an appropriate technique for summarizing costs depends to some extent upon the type of cost analysis being conducted. In the section which discusses various summarizing techniques, the appropriateness of each technique as it may apply to the major types of cost analyses is pointed out.

A brief description of the general content of system costs will serve to aid the discussion of the various summary techniques. One of the first steps in the conduct of a weapon system cost analysis is the preparation of an

appropriate classification of relevant cost elements. Usually costs will divide according to whether they are non-recurring or recurring, and into major categories such as R&D, investment, and operations and maintenance. A consideration essential to the design of an appropriate classification of costs is the way in which one plans to summarize costs. And, of course, relevancy of costs and their classification depends upon the kind of effectiveness comparison to be made.

Generally, elements similar to those listed in table I are included in a weapon system cost analysis (reference (b)). The three major categories follow a chronological order; however, there is usually some overlap. That is, some investment expenditures are incurred prior to the completion of research and development, and operations begin prior to the delivery of all items of prime mission equipment, etc.

There are situations where a categorization like the one shown in table I is less than satisfactory. Take for example the studies conducted on alternative means of placing payloads into orbit around the earth. The item of central concern was the production cost of the boosters needed to launch the payloads, and in most military systems the cost of this item would be considered as an initial investment. In the case of the booster studies, the need for launch vehicles was recurring; (i.e., the boosters were non-recoverable in most cases) and their costs more appropriately fell into the operations category.

And, as another example, the cost of altering ships and their weapons and electronic systems presents a problem of categorization. During her lifetime, a ship may be altered several times; the cost of alterations is therefore recurring, even though not on an annual basis. Cost models which include the cost of alterations as an annual expense are apt to be misused in instances where the cost of procuring the ship and operating it for only a few years is of interest. One may not expect to incur significant alterations costs during the first few years. The point here is that cost categorization is important; categories devised for past studies may contain special implications valid only for those studies.

Selecting an appropriate classification of cost elements as they divide into the 3 major cost categories, and especially between non-recurring and annually recurring costs, is closely related to the way in which one plans to summarize costs for the final analysis. And, it is essential to select a summarizing procedure that appropriately measures those costs associated with the effectiveness measured.

Ideally, one measures costs and benefits (or effectiveness) over the same time period, and year by year. In military systems analysis, it is most difficult to estimate a stream of benefits for weapon systems in a timely and accurate manner. Hence, measures of effectiveness are typically assumed

to apply to one future date. The appropriate measure of resources required to make such effectiveness available at that future date must usually be a compromise between the ideal and the practical.

TABLE I

TYPICAL CLASSIFICATION OF WEAPON SYSTEM COST ELEMENTS

I. Research and Development

1. Preliminary Research and Design Studies
2. Design and Development (Of Subsystems)
3. System Test (Of Complete System)

II. Initial Investment

1. Prime Mission Equipment
2. Support Equipment
3. Initial Spares, Spare Parts and Stocks
4. Initial Training
5. Initial Travel, Transportation, and Miscellaneous
6. Military Installations

III. Annual Operations

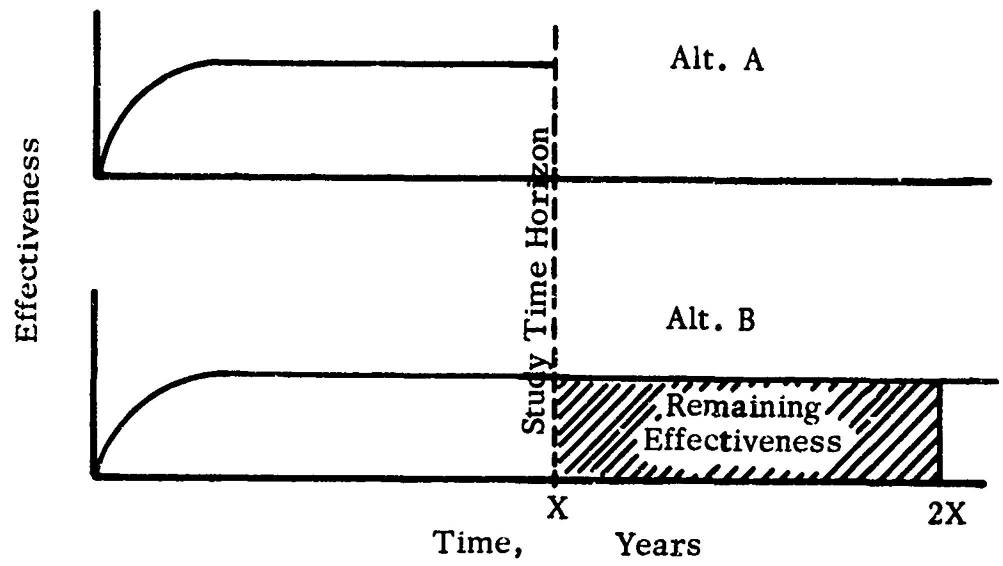
1. Pay and Allowance
2. Equipment and Installations Replacement
3. Equipment and Installations Maintenance
4. Replacement Training
5. Consumables (e.g., fuel, oil, etc.)
6. Recurring Travel, Transportation, and Miscellaneous

REMAINING VALUE

The term remaining value used in the context of defense systems analysis relates to the usefulness or effectiveness of assets still on hand beyond the selected time horizon of a particular analysis or study. Suppose we have two alternatives competing for the same mission, and we estimate their effectiveness versus time curves as shown on the following page.*

Given that our estimates are good, alternative B has potential effectiveness remaining beyond the study time horizon. The problem is to take account, somehow, of the remaining usefulness beyond the somewhat arbitrary study cut-off date. One way to do this is to attach a dollar value to the remaining effectiveness, and credit that amount to the costs of alternative B.

*We could assume one or both systems (A and B) exist, and depict a decline in effectiveness over time.



That dollar value should represent future avoidable expenditures. That is, expenditures needed to maintain alternative-A-type capability from time X to 2X can be avoided if alternative B is selected, and those expenditures are equal to the remaining value of alternative B beyond time X. This of course assumes we will want the capability from time X to 2X. Suppose we are sure we will not want such a capability beyond the time horizon of the study, but we know that some or all of the assets making up alternative B will find a secondary usefulness. Then the expenditures avoided by not having to buy assets for the secondary purpose, but rather by inheriting alternative B's assets, represent the remaining value of alternative B at time X.*

In the marketplace, the remaining value of an asset is also equal to its cost or expenditure avoidance, and that is equal to its salvage or market value. As an example, the remaining value of a 3-year old automobile is equal to the price it will bring on the market. If one desires the service that car provides, then the cost he avoids by retaining it is equal to the cost of buying one just like it. For marketable assets, it is unnecessarily confusing to think in these terms. Conceptually it is much simpler to think of the remaining value of one's old automobile as being equal to the price he can get for it on the market. When considering non-marketable assets, one must focus his attention on a different question, and that is the question of future avoidable expenditures (reference (i)).

*N.V. Breckner and V.L. Broussalian of CNA considered this concept in depth during a study of ship obsolescence, and will soon publish a research contribution on the subject.

The estimation of remaining values of marketable assets sometimes makes use of the methods of depreciation accounting. Lacking something better, the estimation of future avoidable expenditures related to defense systems (comprised largely of non-marketable assets) also relies upon the accounting concept of depreciation, and this reliance has contributed to confused thinking on the issue. This of course does not mean that all those who use methods of depreciation accounting in this context are confused. There are situations in which one of the methods of depreciation accounting may provide an adequate estimate of remaining value, or at least a better estimate than one would have if he ignored the remaining usefulness as depicted in the sketch of alternative B.

Up to now we have been talking about the remaining value of proposed systems at some date in the future. The same concepts attach to the remaining value of existing assets we wish to employ in proposed system alternatives. That is, assets on hand and "available" for use in one or more of the alternative systems being compared obviously have some value or we would not suggest their continued use. However, such assets are generally treated as free, and termed inherited assets.

The comparison of alternative military systems inevitably involves some consideration of the amount of existing assets "available" to proposed systems. A proposed alternative may be such that it can "cash-in" on existing assets. As an example, let's consider the situation where the Navy is in the process of selling surplus vessels to a commercial enterprise; bids are invited and opened. The Navy knows the market value of those surplus ships. Suddenly, the Navy discovers that a proposed weapon system being compared with other alternatives can make good use of them. But it's too late; the bids have been opened, and the Navy is obliged to sell to the highest bidder. The comparative analysis contained an assumption that those ships would be treated as free inherited assets. Now, as things have happened, it is obvious the assumption was invalid. That is, the Navy must buy those ships from the commercial enterprise if they want to use them in the proposed system.

Did the mere act of opening the bids, an act which committed the Navy to sell, change the analytical framework? Not really. It did, however, serve to clarify an issue - the issue that inherited assets frequently have alternative uses and are therefore not free. Even if the Navy had not placed those ships on the surplus market, there was that potential alternative use for them. For example, if the study had discovered a need for those ships before they were put up for sale, the Navy would be giving up an amount equal to the high-bid price if they elected to make those ships available to the proposed weapon system. And that represents a real cost to the Navy.

The question one should ask when estimating the cost of inherited assets is "Do those assets have an alternative use, and if so, at what value?" The essential difficulty with this question is that it is hard to answer. Most military

assets have no market value, and many have nebulous alternative uses. But some military assets have clear alternative uses, and the question should be asked. Most systems analyses avoid the question, and assume existing assets that are candidates for phase-out may be inherited by new systems free of charge. This assumption is perhaps more right than it is wrong; that is, more times than not, the existing assets have no significant alternative use. But we beg the question when we lay ground rules that lead us to fail to ask the question. Each study effort has its own peculiarities, and one never knows when that question may have a highly significant impact on the results.

It has been suggested, at least implicitly, that if we assume inherited assets are free when in fact they may not be, we can make up for this neglect by omitting any consideration of value remaining at the end of the study period, or time horizon. To place credence in this suggestion is to believe that two wrongs make a right. However, it should be out of a desire to simplify an arduous and tenuous task that such a suggestion arises, not out of ignorance to significant economic concepts. The omission of the cost of inherited assets at the beginning of a decision period and remaining values at the end may influence the relative costs of alternatives being compared, and for this reason it is important that some consideration be given their respective values.

The essential difference between the cost of inherited assets and the remaining value at some future date of proposed assets is that it is usually somewhat easier to estimate the former because we can examine existing assets for current alternative uses. And, too, inherited assets generally represent a relatively small proportion of a proposed system's cost, whereas remaining values may be far more significant. Seldom if ever would we desire to fall back on one of the methods of depreciation accounting for an estimate of the cost of inherited assets, though we may occasionally elect to use one of those methods for estimating the remaining value of proposed assets.

The most common meaning attached to the word depreciation is decrease in value (reference (c)). The difference in value at two different dates is the amount of depreciation implied by this concept. And, the decline in value, either market value or value to the owner, is irrespective of the cause or combination of causes responsible for the value change.

Accountants attempt to measure the depreciation of assets by amortizing their original cost; i.e., periodic charges are made in the books of account to recover the original cost of equipment before its useful life is ended. The amortized cost concept of depreciation is radically different from the decline in value concept. The latter attempts to measure the difference in original cost of the asset and its market value. The difference is the amount of depreciation, or appreciation if the asset has a market value in excess of its original cost. The former concept, amortized cost, is an accounting technique designed to record original cost as a charge to income in the books of account over a number of years. The number of years depends upon the estimated useful life of the item (as tempered by considerations listed below), and the amount

of depreciation charged depends on the estimated salvage value and the particular depreciation method selected; i.e., sinking fund, straight-line, declining balance, sum-of-the-years digits, etc.

The objectives of depreciation in accounting are twofold: to allocate the total original cost of equipment to production during the period in which it will be used, and to convert capital outlays into annual expenses allowable for income tax purposes (reference (d)). It is only by accident that such procedures have any meaning in economic thinking; i.e., the actual decrease in value of assets may in some cases be approximated by the use of one of the accountants' depreciation methods. It is most difficult to estimate in advance which technique most appropriately measures the decrease in economic value, for non-marketable assets.

Elements essential to the distribution of original cost over time include the estimated useful life and the approximate relationship between age and remaining value. But the measures assigned to those elements may be entirely different for the two purposes. For example, the estimated life and the method for apportioning depreciation expense are usually selected for depreciation accounting purposes on the basis of considerations such as: (reference (c))

a) Effect on business pricing policies;
b) Comparison of unit cost at different dates for purposes of operating control;
c) Conservation of the financial resources of a business;
d) Effect on income taxation;
e) Effect on regulation of public utility rates;
f) Likely relationship between "book values" (or unamortized cost of assets) and their current values to the owner.

In economic analyses, it should be recognized that estimates of useful lives and of remaining values at any time during the assets' lifetime are highly uncertain. Ideally, they should be the best unbiased (by considerations listed above) estimates the analyst is capable of making, and where future uncertainty looms large, a range of estimates should be examined for their implications. Estimates of economic life should be based on considerations such as: (reference (c))

a) The increase in operations and maintenance cost with age and use.
b) Development of improved alternatives (obsolescence).
c) Changes in requirements.

Obviously, projections deep into the future on such considerations cannot be certain. About the best one can do short of having divine foresight is to use the past as a guide to the future, and combine historical analyses with considerations of the probable influence of new forces which are likely to affect useful lifetimes of assets in the future. Statistical analysis of past retirement experience provides a valuable starting point for estimates of probable lifetimes for new assets; however, it will not usually be possible to separate and quantify the influence of each cause of retirement; for example,

availability of economically better alternatives, change in requirements, wear out, casualty, etc.

Also, estimates of average service lives based on mortality studies of past retirements may be misleading. Wars and depressions of the past greatly influence decisions regarding retirement, and these factors are unrelated to the economy of performance of particular assets. Take for example the history of merchant ships which displays a marked decrease in annual retirements with the period of increased national defense activities in 1940. Every ship afloat was needed to move the abnormally heavy traffic.

The concept of depreciation useful in economic analysis is the decrease in value concept. The value of assets frequently turned over on the market is relatively easy to estimate. Conversely, the value of military assets, seldom if ever sold on the market, is difficult to estimate; that value is best thought of in terms of the remaining usefulness of assets still on hand and expected to be on hand for some time beyond the selected time horizon of a particular study.

Although we have pointed out the fallacy involved in the use of depreciation accounting methods for estimating remaining values of defense systems, there have been occasions when such methods were advocated as a useful and practical dodge. Their use will probably be suggested in the future. If the alternative to using one of the depreciation accounting methods to estimate remaining value is to assume that value is zero, then it is perhaps desirable to use one of those methods if the alternatives have different expected useful lifetimes.

There are many different methods used by accountants to write off costs; the four most commonly known methods span the spectrum of likely relationships of depreciation to age. They are the straight-line, declining balance, sum-of-the-years digits, and the sinking fund methods. The declining balance and sum-of-the-years digits methods write off a greater share of the original cost in the early years of life than in the latter; the straight-line provides a uniform write-off throughout the estimated useful service life; and the sinking fund technique is designed to write off a smaller share of the original cost in the early years of life than in the final years (reference (f)).

The cost analyst using depreciation methods to estimate the portion of original cost to be charged during the time period of his study is interested in calculating the cumulative depreciation charge through the year representing his time horizon. The equations given below allow one to calculate that charge directly.

The symbols used in the equations are defined as follows:

n = number of years from present to time horizon
F = first or original cost
S = estimated salvage value at end of useful life
L = useful life in years
i = depreciation rate expressed as a decimal

In the straight-line method the full useful service life and prospective net salvage value are estimated. Given the first cost of the asset and the number of years to the time horizon, the relationship for the cumulative straight-line depreciation charge through year n (SL_n) is:

$$SL_n = \left[\frac{F - S}{L} \right] n \tag{1}$$

One rationale given for the use of the declining balance method is that assets reaching their final years of usefulness are generally employed in a stand-by or other secondary status. With this method a given rate is applied each year to the unamortized cost (i.e., that portion of original cost not already written off). The rate is sometimes expressed as a multiple of the straight-line rate. For example, an asset with an estimated life of 20 years and zero salvage value has a straight-line rate of 5 percent per year (100%/20 years); the double-rate declining balance method would apply a rate (i) of 10 percent for that asset. Unlike the other methods of depreciation, the declining balance method does not write off all the original cost of the asset, even for those assets estimated to have zero salvage value. That is, the prospective salvage value is disregarded; the rate (i) is calculated as:

$$i = \frac{\text{multiple of straight-line rate} \times 100\%}{\text{estimated life in years}} \tag{2}$$

and the equation for DB_n, the cumulative depreciation charge through year n, is:

$$DB_n = F - F(1 - i)^n \tag{3}$$

Depreciation rates selected for calculation and tabulation as declining balance factors in the appended table A-3 are those needed for lifetime estimates of 5, 10, 15, etc., through 30 years, and for multiples of the straight-line rate of 1, 1-1/2, and 2.

The sum-of-the-years digits method adds the digits corresponding to the number of years of the estimated useful life. In the first year the write off is equal to the fraction of original cost found by multiplying by the estimated useful life divided by the sum of the digits, and in the second year by the estimated useful life less one divided by the sum of the digits, etc. The equation for $SOYD_n$, the cumulative depreciation charge through year n, is:

$$SOYD_n = (F - S) \left[\frac{n(2L + 1 - n)}{L(L + 1)} \right] \tag{4}$$

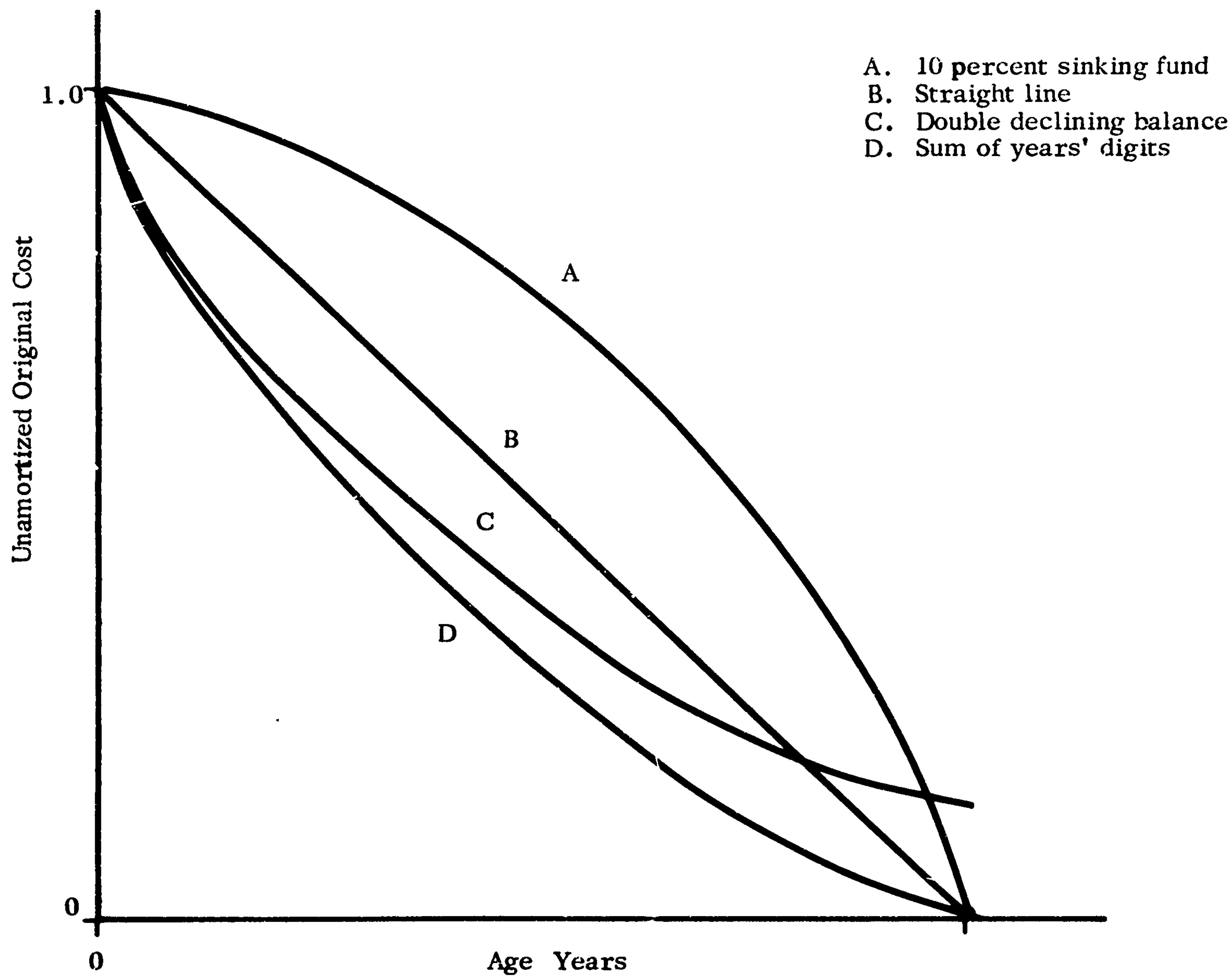


FIG. 1: VARIOUS TECHNIQUES OF DEPRECIATION ACCOUNTING

The above method writes off about three-fourths of the cost in the first half of the estimated useful life.

The sinking fund method writes off less cost during the first half of life than in the last half. Imagine a sinking fund into which uniform end-of-year payments are made during the lifetime of the asset. Assuming the deposits draw interest at rate i, the depreciation charge in any one year is equal to the sinking-fund payment plus interest on the imaginary accumulated fund. The cumulative sinking fund depreciation charge through year n (SF_n) is found by solving:

$$SF_n = (F - S)\left[\frac{i}{(1+i)^L - 1}\right]\left[\frac{(1+i)^n - 1}{i}\right] \qquad (5)$$

Interest tables may be found in books of investment, finance, accounting, mathematics, economics, etc., which aid the solution of the cumulative sinking fund depreciation charge. Grant's book contains interest tables listing factors useful to the solution of the above relationship, and they are titled: (reference (f))

$$\frac{i}{(1+i)^L - 1} = \text{sinking fund factor, uniform series} \qquad (6)$$

$$\frac{(1+i)^n - 1}{i} = \text{compound amount factor, uniform series} \qquad (7)$$

The appendix to this document contains a set of interest factors which, with a few more calculations than with Grant's tables, may be used to solve the sinking fund equation, and to solve the relationships given in the next section having to do with the time value of money. The appended tables (A-1 and A-2) give factors for the expression $(1+i)^n$, the single payment compound amount factor, and $(1+i)^{-n}$, the single payment present cost factor.

Figure 1 shows the general shape of the curves describing each method of depreciation discussed in this section.

TIME VALUE

Economic analyses of defense systems sometimes employ a technique called discounting. The reasons for and against discounting streams of costs in defense systems analyses are currently controversial among economists, and the appropriate rate at which such streams should be discounted is even more controversial.

It is not the purpose of this section to discuss the issues involved, but to briefly explain the application of the mathematics of investment to problems of defense cost analysis. Discounting techniques do find use in the Department of Defense and in other government agencies; however, their use is less common

in ne public sector than the private, and this is so because the controversy appears to focus on non-marketable assets.

Most notably among those who suggest the use of positive discount rates is Mr. Charles J. Hitch, formerly Assistant Secretary of Defense-Comptroller. In his book co-authored by Roland N. McKean of the Rand Corporation, The Economics of Defense in the Nuclear Age, (reference (e)), it is suggested that costs and benefits be stated in terms of their present value. He goes on to say that an appropriate rate of interest depends upon the particular circumstances; 3 percent is suggested as a minimum, and 20 percent as an extremely high rate to use. To avoid quoting out of context, the following excerpt is felt necessary:

C.F. Hitch and McKean, R.N., The Economics of Defense in the Nuclear Age, Harvard University Press, 1961, pages 209-211.

"The straightforward (but not necessarily the easiest or preferred) way to make costs and benefits at different times commensurate is simply to apply an appropriate discount rate to future costs and benefits, so that all are stated in terms of "present value." This is what a business firm does, at least implicitly, in comparing present and future amounts, preparatory to choosing policies that maximize present value. But what is the "appropriate" rate for this discount calculation? In general terms, the rate should be the marginal rate of return that could otherwise be earned - that is, the rate that reflects the productivity of the next-best opportunity. If the investor can borrow and lend freely, the marginal opportunity will turn out to yield approximately the market rate of interest. If he faces a fixed budget, the marginal opportunity may yield some other rate. If legal or other constraints close off certain opportunities, those investments are simply not relevant and have no bearing on the selection of the rate of discount.

"It is often argued that governments should not discount future amounts at as high a rate as do individuals and firms, because governments should take a longer-run view and endeavor to provide more for posterity than the decisions of private individuals would provide. We may indeed want governments to take a long view and to make extra provision for later generations - by increasing total public investment (in either defense or other forms) or by stimulating private investment. But, having settled this issue, governments should presumably try to channel the investment funds into those activities that have the highest rates of return. Similarly, an individual who wishes to provide more for his heirs should cut his consumption and raise his total investment, but should channel his capital into its most productive uses. In either instance, this means discounting streams of cost and gain at the marginal rate of return, not at some artificially low rate.

"In government, the marginal opportunity depends upon the problem of choice that is being considered. Usually, when we look several years ahead, leaving

the resources in the private economy is a pertinent alternative, one that may be taken to be the marginal opportunity. In other words, the government can repay debt or refrain from borrowing or taxing instead of making the purchase under consideration. *As a consequence, the rate the government has to pay to borrow funds - on the order of 3 percent - is a suitable minimum rate.* (Italics Added) If leaving the resources in the private economy is not an admissible alternative - if the problem is to allocate a given budget - the marginal opportunity and yield may be something else.

"As suggested previously, however, we usually have to add an appropriate risk premium to this minimum rate. We should allow to some extent for the chances that the future benefits we expect may never be realized, that the costs may not have to be incurred, and that the estimated amounts may turn out to be wrong. But we do not know and cannot hope to learn precisely how risky any particular military investment is.

"Some investments are certainly riskier than others. The probability of war (or peace) breaking out before realization of the anticipated benefit or cost is probably similar for all military systems; but some systems will be more vulnerable than others to uncertainties about technological advances, future strategic situations, and enemy capabilities and intentions. Advanced weapon systems, such as a future hypersonic long range bomber, appear to be among the riskiest enterprises of the modern world. Airlift systems like those compared in chapter 8 appear to be much less risky. Technological advances in economical air transportation occur more slowly than in offensive and defensive weapon systems, and it seems likely that we will be able to use a lot of economical air transportation for something important through the 1960's even if technological or political developments rule out the danger of limited warfare in the vicinity of Bangdhad.

"Perhaps, therefore, an appropriate discount rate (pure interest plus risk premium) for a military investment like that in airlift capacity would be similar to a rough average in private enterprise - *say 6 to 8 percent per annum; while the appropriate rate for an advanced weapon system might be higher - say 10 percent or more.* (Italics Added) Twenty percent would be an extremely high discount rate to use; it reduces a cost or benefit anticipated 5 years hence to almost a third its nominal value, and one anticipated 10 years in the future to about a sixth. If risks are *really* high enough to justify a 20 percent discount rate, investments whose payoffs are in the distant future can rarely be justified unless the nominal payoffs are spectacular. *The appropriate discount rate during World War II appeared to be even higher than 20 percent because immediate results were so much more important than distant payoffs; so we required that development and procurement be justified on the basis of payoff during a very short period.* (Italics Added)

It is pretty clear that a rate as high as 20 or even 15 percent per annum could not be justified in present circumstances (1960) by the probability that

war will intervene. (Italics Added) Of course if our assessment of the probability of war increases, we should both increase military expenditures and use a higher discount rate in choosing among alternative purchases."

On page 213 Hitch adds:

"Because of uncertainties about future costs and capabilities, it is not worthwhile to devote an inordinate amount of time to refining one's estimate of 'the' proper discount rate. Historical studies show that projections of cost and performance of weapon systems, particularly those made at early stages of development, have often been wide of the mark. For systems analysts to put great effort into determining 'the' discount rate would probably be less productive than other uses of their time." (Italics Added)

"Moreover, because of uncertainties about future budgetary constraints and hence about marginal opportunities and their yields, the discount rate that may later be appropriate is inevitably in doubt at the time choices must be made. The best estimate may simply be a rough average rate of return in the private economy, like 6 or 8 percent. This rate would include an average allowance for risk. Special degrees of risk associated with particular weapon systems should be pointed out by the analyst but would have to be allowed for subjectively by the final decision maker." (Italics Added)

Within the Defense Department, one may find proponents of discount rates varying from a low of zero to in excess of 20 percent. The point is that just as estimates of future costs and benefits are necessarily uncertain, (reference (g)), so are estimates of discount rates. That being the case, it seems advisable to examine alternative cost streams for sensitivity to varying rates. Ultimately it is the decision maker who will make a judgement regarding uncertainty in this rate as in other variables.

Hitch and McKean suggest that a rate of 6 to 8 percent, which includes an average allowance for risk, may be the best estimate for purposes of quantifying an analysis. Sobin recommends a basic interest rate of 5 percent (reference (k)). Others suggest the appropriate risk-free rate is equal to the government-guaranteed rate of return before taxes allowed monopolistic public utilities, and that rate is about 10 to 12 percent. Still others suggest there is no reason to discount streams of costs of public alternatives unless certain very special assumptions are made, and then the appropriate rate is equal to the borrowing rate, or about 3 percent. The controversy exists in spite of the tremendous amount of thought and work given the subject; it is not likely to be solved in the near future. To ignore the existence of the time value of money is not an interim solution; to examine alternatives for sensitivity to time value may be the best we can do for some time.

Resources are said to have time value because they have the capacity to earn a net return in alternative uses. Similarly, money is said to have time value because we are willing to pay for the use of borrowed money. The amount we are willing to pay is called interest, and the rate at which we are willing to pay is usually described as an interest rate per annum, although the rate may be per any time period. In a competitive industrial society such as ours, businessmen must and do recognize the time value of money. Individuals do as well. When you deposit money in a savings account to earn interest at 3 percent per annum, you have placed a time value on your money. The probability is very high that you will get exactly 3 percent per annum compounded periodically when you place your money in the savings account of that bank. There is almost no risk of loss. On the other hand, when you buy stock in a company paying dividends at the rate of three percent per annum, you have accepted a risk albeit difficult to measure. There is the risk that you will have to sell your stock at a time when its price is lower than the original purchase price; there is the risk of bankruptcy. On the other hand, there is the chance that you may realize sizable capital gains by selling the stock at a time when its price is considerably higher than the price you paid for it. The average return on industrial stocks during the past decade is estimated to be about 9 percent; the difference between the "no-risk" savings account investment and the "some-risk" investment in stock is the approximate return one gets on the average for taking this particular risk.

Interest is then the price one is willing to pay to have money made available to him for a certain amount of time; or the price at which one is willing to sell the availability of his money to someone else for a given amount of time. These two prices as measured in interest rates must be equal to successfully result in a transaction. The higher the expected risk of loss of return, the higher the interest rate demanded by the lender.

Risk premiums added to the interest rate to account for future uncertainties often work in just the opposite direction from that meant. For example, suppose we are comparing two systems whose cost streams are identical, and whose benefits are expected to be the same. We judge the first system to be less risky than the second, so we decide to assign the first a 5 percent rate and the second a 10 percent rate of interest for our discounting calculation. If we were then to select from the two alternatives the one with the lowest present cost, we would choose the alternative with the greatest risk. This is obviously not what is intended. The risk premium attaches to the stream of expected benefits, an earned return on investment in the example cited above. If one is attempting to account for the risk that costs are erroneously estimated, then one would expect to employ a technique which inflates rather than deflates costs because it has been shown that weapon system costs are generally underestimated (reference (g)).

Broussalian discusses this point and others in two papers (references (h) and (i)). Briefly, his point of view is that future expected defense expenditures should not be discounted at all. The decision maker must make up his own mind as to his time preferences among expenditure streams of specific proposals, and such a time preference cannot be adequately reduced to discount rates, and especially to rates which include risk premiums.

The popular meaning of a discount in the retail market is the amount deducted from the regular price of an item. The interest deducted in advance by one who lends money on a promissory note, or other collateral, is also known as a discount. As an example of discounting used in the latter sense, suppose you ask to borrow $1500 from your bank to buy an automobile. Your banker offers you the following deal: interest at 5 percent per annum, and a monthly repayment period of 2 years. One way (undesirable from your point of view) for the banker to calculate your cost of the loan is to take two years times the annual interest rate (2 x 5% = 10%), and multiply this product times the amount of the loan (10% x $1500 = $150). The result, $150.00, is then the amount he discounts or deducts in advance from the face value of the loan. So you walk out of the bank with $1350, and you have given your promise to repay $1500 over a 2-year period at $62.50 per month. (1500/24 = 62.50). But the principal owing is the full $1350 for <u>one</u> month only, after which it is progressively reduced. There is a sharp difference in the cost of your auto loan figured in this way and the cost of your 5 percent home mortgage. Home mortgage loans usually charge interest on the unpaid balance at the end of each repayment period, and the charge is called <u>effective interest</u>.

Application of financial mathematics to time-phased costs for the purpose of making costs commensurate at different times makes use of effective rates of interest. Referring again to the auto-loan example above, the banker has traded $1350 now for the promise of $62.50 per month for 24 months. If the banker had made his transaction on the basis of a stated effective interest rate (i.e., interest on the unpaid balance) then the present value of the repayment stream of $62.50 per month for 24 months would be just equal to the amount he gave up. But it is <u>not</u>; the present value of the repayment stream at 5 percent per year compounded monthly (or 5/12% per month) is about $1425. The rate of interest which makes the present value of the repayment stream just equal to $1350 exceeds 9 percent, and that is the effective rate of interest paid by the borrower in this case.

Techniques for calculating the time value of money are embodied in the mathematics of investment, and the procedure for finding the present value of a stream of costs (called present cost hereafter) is generally referred to as <u>discounting.</u> The formula for discounting a stream of costs from the present through year n where the costs are end-of-period sums is:

$$P = \sum_{j=0}^{n} S_j (1+i)^{-j} \qquad (8)$$

where,

i = interest rate per interest period

n = number of interest periods

P = present cost

S_j = sum of costs incurred during period j

The above relationship involves some tedium; that is, to find the present cost of a stream of costs one must apply the appropriate factor, $(1+i)^{-j}$, to each period's sum, S_j, and then add the results of the series of multiplications. When the time period under consideration is long, say 15 to 20 years, and the number of alternatives numerous, many calculations must be made. In the estimation of total time-phased system costs as currently prepared within the Defense Department, the annual costs are usually predicted to be constant after the system has reached its full force size. Therefore, annual costs estimated during the last 10 to 15 years of the time period may be equal annual costs (R) and the following formula allows one to convert that uniform annual series to present value (reference (f)):

$$P = R \left[\frac{(1+i)^n - 1}{i(1+i)^n} \right] \qquad (9)$$

where,

R = Uniform series of end-of-period sums equivalent to present value P with interest i for n years

Suppose the uniform series of annual costs begins in the fifth period; the application of equation (9) allows one to find the present cost of that uniform series where the present is defined to be the end of the fifth period, and the resulting present cost may now be called S_5; it is then necessary to find the present value of S_5. The interest table in the appendix aids the solution of all interest formulas given in this section; Grant's (reference (f)) tables make their solution even simpler from the standpoint of the calculations involved.

Occasionally it is desired to convert the present value of a cost stream into an equivalent uniform annual series. The conversion adds nothing to the analysis, nor does it change relative present costs from one alternative to another. It is however sometimes less cumbersome to use. The equation for finding the equivalent uniform annual cost is (reference (f)):

$$R = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \qquad (10)$$

An example will serve to illustrate the use of the equations and the tables. Suppose a defense system is estimated to cost $100 million broken down as follows:

Year	R&D	Investment	Annual Operations	Total
S_1	5	-	-	5
S_2	10	-	-	10
S_3	2	3	1	6
S_4	-	13	5	18
S_5	-	20	6	26
S_6	-	-	7	7
S_7	-	-	7	7
S_8	-	-	7	7
S_9	-	-	7	7
S_{10}	-	-	7	7
ΣS_j				100

Assuming the above costs represent end-of-year payments, and our objective is to find the present cost and the equivalent uniform annual cost with interest at 10 percent, we may proceed as follows: first, find the present cost of each sum appearing in the total column for years S_1 through S_5, the years in which the costs are not uniform. Using equation (8) and the tables appended:

$$
\begin{aligned}
P_{S_1} &= S_1(1+i)^{-j} = 5(1+0.10)^{-1} = 5\,(0.9091) = 4.5455 \\
P_{S_2} &= \phantom{S_1(1+i)^{-j}} = 10(1+0.10)^{-2} = 10(0.8264) = 8.2640 \\
P_{S_3} &= \phantom{S_1(1+i)^{-j}} = 6(1+0.10)^{-3} = 6(0.7513) = 4.5078 \\
P_{S_4} &= \phantom{S_1(1+i)^{-j}} = \phantom{6(1+0.10)^{-3}} = 18(0.6830) = 12.2940 \\
P_{S_5} &= \phantom{S_1(1+i)^{-j}} = \phantom{6(1+0.10)^{-3}} = 26(0.6209) = \underline{16.1434}
\end{aligned}
$$

$$\sum_{j=1}^{5} P_{S_j} = 45.7547$$

Secondly, we can find the present cost of the uniform series over years 6 through 10. One could continue to apply the factors of equation (1) to the sum in each of those years, or one may use equation (2). Probably the most straightforward method is the latter; that is, find the present cost of a uniform series of payments equal to \$7 for 10 years at 10 percent, and subtract the present cost of a uniform series of payments of \$7 for 5 years:

$$\sum_{j=6}^{10} P_j = 7\left[\frac{(1+0.10)^{10}-1}{0.10(1+0.10)^{10}}\right] - 7\left[\frac{(1+0.10)^{5}-1}{0.10(1+0.10)^{5}}\right] =$$

$$7\,(6.144) - 7\,(3.791) = 16.471$$

With the aid of the tables, the above procedure requires the use of 2 factors whereas equation (1) would have required 5. If the time period under consideration were 20 years rather than 10, the latter procedure would clearly be even more desirable.

The present cost of the entire stream is the sum of the P_j's found above, 45.7547 plus 16.4710, or about 62.2. Factors in the tables have been rounded; therefore, calculation of results using 2 different procedures will not necessarily give precisely the same results. Precise discounting of estimated costs of weapon systems is of course unwarranted.

The equivalent uniform annual cost of the stream is found merely by dividing the present cost by n, in this case 10 years. But suppose we have a cost stream comprised of \$100 now and \$10 per year for the next 30 years. We want to know the equivalent uniform annual cost with interest at 10 percent; the simplest way is to convert the initial payment, \$100, to its equivalent uniform annual recovery amount using equation (3), and to this amount add the annual \$10 payment:

$$R = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] + \$10 = \$100\,(0.16275) + \$10 = \$26.275$$

The incidence of cost from one time period to another, usually from year to year, may be an important consideration to systems analyses; the annual incidence of costs of alternatives provides for a more complete comparison of relative merits than does the single figure, total system costs. The need to examine cost streams of competing systems encourages the analyst to time-phase system costs as on page 22. Nevertheless, for the sake of simplicity and understanding of final results, military systems analyses usually reduce total system costs to a single figure for each alternative system. There are many ways one may summarize costs, and several methods commonly used are discussed in the next section.

SYSTEM COST SUMMARIZING TECHNIQUES

The answers to several questions bearing on the objectives of a systems analysis are involved in the selection of a useful method of specifying and summarizing total system costs. For example, during what time period are the benefits being measured presumed to apply? Will measures of system effectiveness (or benefits) be made over a span of time, or will the measures apply to one specific time in the future? Consideration must be given to the question of expected useful lifetimes of the competing systems, etc.

Adequate guidelines for a cost analysis can come only after careful consideration of many questions, only a few of which are mentioned above. Selection of appropriate guidelines, including the way in which costs should be summarized, is best accomplished as a joint effort between the cost analyst and the effectiveness analyst.

Suppose a military systems analysis is being designed to examine the relative merits of systems competing for a given mission. Further, suppose we are fairly certain to have a need to fulfill that mission for 5 years beginning 5 years hence, and all conceived alternatives are just capable of meeting those time constraints. That is, each alternative competing for the mission may be developed and procured in sufficient time to be operational 5 years hence, and each one is estimated to have a useful operational life of 5 years. Also, at the end of the 5-year operational period there would be no further need for any of the systems, and none would have a significant secondary use or scrap value. To complete our description of the best of all possible analytical worlds, let us further assume that the cost and effectiveness streams estimated for each competitor are insensitive to time value; that is, reducing those streams to present value does not change their relative positions. In such a rare situation as this, an adequate cost analysis should simply attempt to capture all incremental costs over the next 10 years only and the task is done; there is no need to time-phase the costs for purposes of discounting, and there is no need to attempt to estimate remaining values.

It is indeed rare to find questions of military resource allocation capable of being reduced to such simplicity on all matters and still contain sufficient realism to make the results credible. Change one of the simplifying assumptions and one must contemplate adopting a summarizing technique which is sensitive to that change.

Five techniques for summarizing total systems costs are discussed in this section. The selection of any one of these dictates the major guidelines for a cost analysis. The decision to use one versus another should not be made lightly but it should also be recognized that no one of them represents an infallible approach to defense cost analysis. Each one contains certain simplifying assumptions some of which are explicit and others implicit.

The 5 techniques selected for discussion here are examples popularly employed within the Department of Defense; also, there are many variants to those listed here which find some use. The variations are relatively minor, and it is believed the spectrum of methods used to summarize total system costs is encompassed by these 5:

1) Five-year system cost

2) Period outlay

3) Net cost

4) Present cost

5) Annual cost

All techniques discussed employ the constant dollar as a unit of measure. The reasons for this procedure are that our main concern is the estimation of relative costs, and that as far as society is concerned the basic interest is the proportion of real resources to be diverted from the private sector of the economy to the defense sector. The dollar cost is used simply as a measure of resources needed to develop, procure, and operate a system, not the extent of the monetary liability. It allows us to state in common units the sum of the many dissimilar resources required. Use of the constant dollar is the usual procedure for measuring the real resources needed for achieving the prescribed objectives. There may very well be special situations where the omission of price level changes would cause difficulties. This is not generally the case in defense systems analysis where it would be quite risky for the country to commit itself to a fixed dollar expenditure rather than a fixed resource expenditure.

Each one of the techniques listed above is discussed in turn giving their distinguishing characteristics.

Five-Year System Cost. A common technique for comparing costs of alternative systems is to add to the research and development and initial investment the costs of operating each system for 5 years. First introduced by the Rand Corporation, it has since become known as the 5-year system cost.

Characteristic of this method is the omission of costs associated with the build-up of forces. That is, operating costs based upon a full force size are estimated, and it is assumed that the operating costs will not vary with time. Thus, having estimated the cost of operating the defined force for one year it is necessary only to multiply the annual cost by the number of years of interest to find the total operating costs. As commonly used this method employs 5 years of operating costs. There is nothing inherent in the approach requiring the use of 5 years rather than say 4 or 6. A number of years sufficient to capture a representative amount of operating costs relative to the non-recurring costs is the basis for selecting 5; the hope is that relative costs of alternatives is not unduly influenced by the selection.

The selection of 5 rather than say 30 years is undoubtedly due at least in part to the knowledge that Air Force missile and aircraft systems of interest to studies engaged in by the Rand Corporation have a useful lifetime much closer to 5 years. An interesting question is, "Would our most common summarizing technique be a 30-year system cost if those systems of interest to the Rand Corporation had generally experienced useful lifetimes approximating 30 years?" Probably not; problems of time value and distant future uncertainties would have presented implications much more serious and generated the need for much more thought than has been given the subject by those espousing the use of the simple 5-year system cost technique.

Costs are not related to time, or time-phased, as a usual and integral part of the 5-year method. It is necessary to estimate delivery schedules and costs associated with the procurement or build-up phase to adequately state costs in terms of their relation to time. The 5-year technique excludes build-up costs.

No allowance is made for treating alternative systems having different estimated useful lifetimes. Of course, a simple variant to the approach would allow the treatment of unequal lifetimes. For example, those systems having lifetimes estimated at longer than 5 years could be credited with the value remaining after 5 years. Such a procedure is not however commonly associated with the 5-year method; and as defined in this document, the quantitative estimation of remaining values is peculiar to the net cost techniques described below.

Because costs are not time-phased, the details underlying the 5-year system cost do not lend themselves to discounting, and therefore the time value of money is not recognized. Very crude approximations to the present value of costs are sometimes calculated assuming the non-recurring costs occur now and the operating or recurring costs occur during the 5 years immediately following. But as pointed out in the next section, such an assumption is misleading.

The main advantage attached to the use of the 5-year system cost technique is its simplicity. A side benefit is that its simplicity allows the cost analyst to concentrate his attention on estimates of major costs to the exclusion of seemingly minor ones. The danger of course is that the seemingly minor costs (e.g., build-up costs) may turn out to be significant in the comparison. And, the omission of time value and unequal lifetime considerations may in some cases be serious.

The technique is designed to be used with individual weapon systems cost analysis as opposed to mission-area or total force structure analysis.

Period Outlay. Fundamentally, the period outlay method is similar to the 5-year approach except that it includes costs incurred during the build-up or phase-in period. Costs are generally time-phased on the basis of specified delivery schedules, but the cost streams are not discounted; however, the basis for an examination of the sensitivity of costs to time value and remaining value is usually provided by the inputs needed to conduct a period outlay analysis.

The time horizon selected for study is flexible; i.e., it is selected to bear some relationship to the expected useful lifetimes of the systems compared. If one system has a longer life than another, the lifetime of the shortest-lived system dictates the maximum time horizon, or latest cut-off date. This is done to avoid having to assume a follow-on procurement for the short-lived system. Remaining values of the longer-lived systems are recognized by listing the age of assets expected to be in service as of the study cut-off date. Such a list is given in lieu of, rather than in addition to, the calculation of remaining values made on the basis of some arbitrary depreciation accounting method.

The word outlay as opposed to cost is used in the name of this technique to bring out a salient difference between this and other procedures. All the other techniques addressed in this document purport to measure costs of acquiring and maintaining a defense system. And costs are meant to capture relative amounts of resources required by alternative systems. The period outlay method makes no pretense at measuring quantitatively the relative amounts of resources needed. The systems with relatively long expected useful lifetimes are penalized when the time horizon is taken as equal to the lifetime estimate of the shortest-lived system. This is true because the long-lived system still has some value the cost of which has been included, but the short-lived system has essentially no value remaining.

The period outlay method has found use in a comparison of airlift and sealift alternatives. The prime mission equipment in the airlift alternative (i.e., aircraft) have expected useful lives on the order of 10 to 15 years; the major equipment items providing sealift (i.e., ships) are expected to be useful 2 to 3 times as long. The time horizon selected for the study coincides with that date by which the alternatives have operated at a full force level for 10 years. Ten years was selected to avoid replacement of the aircraft. Obviously, such a procedure penalizes the sealift system.

Credit for the remaining life, or value, of the sealift system is treated subjectively by listing the ships and their respective ages at the end of the study period. The tactic here is that if one can show quantitative merit for the longer-lived system or alternative after accepting the penalty of the short time horizon, then any consideration of remaining value would tend to make the longer-lived system even more attractive. There would be nothing gained by estimating remaining value.

The effect of the period outlay method insofar as what is quantified is to impute equal lifetimes to the alternatives. The problems associated with estimating remaining values are not solved; however, the information given the decision maker may in some cases be more enlightening than if one arbitrarily credited remaining values on the basis of one of the depreciation methods.

One advantage of the period outlay technique is that it produces time-phased costs, and the impact on future fiscal year budgets may be examined. Another is that highly uncertain values of the assets remaining at the end of the study period are not credited to the long-lived system. The values attached to the remaining assets are left to the decision maker, and he is given the age of the assets to aid his judgment.

In comparison where the values of remaining assets influence the choice of alternatives, even though a wide range of remaining values may be attached to each estimate, usefulness of the period outlay technique becomes marginal. In such a situation, a controversy would very likely focus on the most appropriate estimate of remaining value, and the net cost technique discussed below would be put to use.

The presentation of costs in terms of period outlay lends itself to mission-area and total force structure cost analyses.

Net Cost. A less common but not uncommon technique for summarizing comparative systems costs is termed net cost. The characteristic distinguishing it from the ones discussed above is that remaining values as of the study cut-off date, or time horizon, are netted out of period outlay. The net cost variant may be applied to either the 5-year system cost or the period outlay methods. Of course, if one plans in advance to employ the net cost technique, his selection of an appropriate time horizon may be different from that if he plans to use one of the other techniques.

In a CNA study of land-based versus sea-based tactical aircraft systems it was decided at the outset to employ the net cost technique. Major equipment items of interest to the study included Air Force and Navy tactical aircraft, and aircraft carriers. Because the study was conducted for the Navy, it was further decided to frame all uncertain assumptions in favor of land-based systems. Useful lifetimes of the tactical aircraft were realistically estimated to be 7 years, and for the carriers a pessimistic estimate of 15 years was used. The time horizon was selected to capture a representative number of years of operations for the last carrier proposed to be built. The study cut-off date became 1981. Costs were estimated and time-phased on the basis of proposed aircraft delivery schedules and carrier shipbuilding programs. It was necessary to assume a follow-on procurement of aircraft because of the distant time horizon selected for the study. And because production of aircraft and construction of ships in numbers of interest to the study takes place over a number of years, there were aircraft of the follow-on procurement whose ages

were less than 7 years and aircraft carriers less than 15 years old as of 1981. So in this particular study remaining values of both the aircraft and the carriers were estimated and credited, and the straight-line method of depreciation was employed to calculate those values.

In the example cited, there are two major simplifying assumptions. First, it was assumed that the follow-on procurement of aircraft would repeat the cost history of the initial procurement, and second it was assumed that the straight-line method of depreciation gave results adequately approximating remaining values of aircraft and ships. Sensitivity of costs to the estimation of remaining values was examined.

The tactical air warfare study, because of their detailed treatment of production and construction schedules, included time-phased costs. The annual incidence of costs is considered in this document to be an integral part of the net cost procedure.

An advantage of the net cost procedure is that it contains provisions for recognizing estimates of useful lifetimes which vary from one alternative to another. One of the methods of depreciation accounting discussed in the section on remaining value is usually employed, and the disadvantages associated with those methods apply to the net cost technique.

This technique finds use mainly in individual weapon system cost analysis, but has also been employed in the cost analysis of the tactical air warfare mission area.

Present Cost. The essential features distinguishing the present cost technique from those discussed above is that cost streams are discounted to their equivalent present values, and the time horizon is selected to be equal to the least common multiple of estimated useful lifetimes of the alternatives being considered. Necessary to the use of the present cost technique is the estimation of the periodic incidence of costs. Annual estimates are usually prepared, and per annum discount rates are stated.

A crude approximation to present cost is sometimes prepared as a variant to the 5-year system cost; it is assumed that all non-recurring costs are incurred in the present and the annual costs are incurred during the next 5 years. The adequacy of this procedure depends upon how closely the assumed time-phasing approximates the actual cash flow. The cash flows for most defense systems are poorly approximated by the above assumption, and misleading conclusions may derive from the calculation of present costs at various rates of interest. For example, a rate of 15 percent applied to the 5-year systems costs may be the equivalent of a 5 percent rate applied to a carefully prepared phasing of estimated costs. (See next section)

The net cost technique may also be modified to include a calculation of present values of cost streams. The present value of the estimated remaining value is found, and subtracted from the present value of the cost stream. When employed in this manner, the disadvantages associated with the explicit estimation of remaining values accrue to this variant.

As defined here, the present cost technique addresses a time period equal to the least common multiple of estimated useful lifetimes of the alternatives under consideration. When one employs the least common multiple of lifetimes, a simplifying assumption must usually be made: that replacement systems (e.g., second and third generation systems) will cost the same as the system replaced. As with all cost summarizing techniques, alternatives should be compared on the basis of providing service over the same number of years, and more precisely, over the same years.

For example, suppose alternative A is estimated to have a useful life of 10 years, and B a life of 15 years. The least common multiple is 30 years; to provide 30 years' service will require 3 A's or 2 B's. The 2 alternatives proposed to fill our needs in the first period are usually specified in some detail, and their costs may be estimated with relatively high confidence. The configuration of the alternative to be selected 10 years from now to replace A, or 15 years from now to replace alternative B, is not known. In the case of weapon systems, it is generally infeasible to project far into the future the specifications of replacement systems. Hence, the simplifying assumption is usually made that the costs of A and B will be repeated. Such a simplifying assumption should not be made without giving some consideration to the prospect that improved alternatives or changes in service requirements during the life of the shorter-lived alternative may occur. That is, the shorter-lived alternative is on the average more up to date.

A recent CNA nuclear power study employed the present cost technique. A comparison of relative merits and costs of nuclear versus conventional power for aircraft carriers was of concern. The annual incidence of costs may be significant to a study expected to need relatively high initial outlays for one alternative compared to another. That is what was expected to occur in the comparison of nuclear versus conventional power. The cost of fossil fuel on a "pay-as-you-go" basis, among other things, was not expected to offset the relatively high initial cost of nuclear cores providing fuel sufficient to last a number of years. Expected outlays through 1990 were estimated; values remaining in 1990 were neglected, and alternative cost streams were discounted at rates varying from zero to 10 percent.

Alternatives equal in cost at zero percent interest showed slightly higher relative costs for the nuclear-powered alternative when discounted at positive rates of interest. Contrary to expectations, the magnitude of change in relative costs was small.

Annual Cost. As defined here, when used to compare alternatives this summary employs the features of the present cost technique specified above; i.e., least-common-multiple lifetimes and discounting of forecasted streams of cost. The annual cost technique reduces total system costs to their equivalent uniform annual amounts as an alternative to the present value above. (The term annual cost is used here to mean equivalent uniform annual cost.) This technique is an extension of the present cost method when interest rates are positive; when interest is assumed to be zero it gives relative results identical to those found using the net cost technique with remaining value computed by straight-line depreciation arithmetic.

In its simplest form (i.e., assuming the appropriate rate of interest is zero) the annual cost of any given system may be found merely by dividing total cost by the number of years included in the analysis. For example, take a system whose 5-year cost is estimated; the annual cost of that system is equal to the 5-year cost divided by 5 years. An example illustrates the similarities between annual cost with interest at zero percent and net cost with straight-line depreciation:

Alternative	A	B
Investment, $	100	60
Operating cost per year, $/yr	2	3
Lifetime estimate, yrs	10	5
Annual Cost, 0%		
Investment per year, $/yr	10	12
Operating cost per year, $/yr	2	3
Annual Cost, uniform equivalent	12	15
Net Cost, Five Years Service		
Amortized investment, straight-line, $	50	60
Five years' operating cost, $	10	15
Net Cost for 5 years	60	75

Notice that 5 years times the annual cost for alternatives A and B are exactly equal to respective net costs for 5 years in the above example.

In the example below, the relationship between annual and present cost is shown. Suppose we are considering 2 alternatives; A is estimated to have a useful service life of 3 years and alternative B 6 years. The initial cost of A is estimated to be $100 and for B $200; their operating costs are estimated to be equal at $10 per year. Assume the appropriate rate of interest is 6 percent per annum. Using equation (3) and the appended tables we may find the annual cost of each system independently:

$$R_A = \$100 \left[\frac{.06\,(1.06)^3}{(1.06)^3 - 1} \right] + \$10 = \$100\,(0.37411) + \$10 = \$47.41$$

$$R_B = \$200 \left[\frac{.06\,(1.06)^6}{(1.06)^6 - 1} \right] + \$10 = \$200\,(0.20336) + \$10 = \$50.67$$

Notice that in the above example there is no explicit statement regarding the assumption that the cost history of alternative A must be repeated to obtain service for a second period of 3 years. However, that assumption is implicit, for purposes of a systems comparison, unless some other prediction is made explicit. The cost streams described in the example are as follows:

End of Year	Now	1	2	3	4	5	6
Alternative A	\$100	10	10	110	10	10	10
Alternative B	\$200	10	10	10	10	10	10

The present value of these cost streams may be found using equations (1) and (2) and the appended tables:

$$P_A = \$100 + \$100\,(1.06)^{-3} + \$10 \left[\frac{(1.06)^6 - 1}{0.06(1.06)^6} \right] = \$100 + \$100\,(0.8396) +$$

$$\$10\,(4.917) = \$233.13$$

$$P_B = \$200 + \$10 \left[\frac{(1.06)^6 - 1}{0.06\,(1.06)^6} \right] = \$200 + \$10\ (4.917) = \$249.17$$

Notice that relative costs of alternatives A and B are the same whether stated in terms of annual or present costs. Hence the only advantage of the annual cost technique over present cost is that for certain cost streams the former technique involves a simpler set of calculations. A disadvantage is that it may tend to conceal the assumption that service over the same number of years is implied for all alternatives; however, the assumption is valid and should usually be made.

A study currently underway at CNA is examining the relative merits of several alternative anti-air warfare weapons deployed aboard escort ships. The size of the escort ship and other characteristics regarding its design

depend upon the characteristics of the weapon. Weapons generally become obsolete long before the vessel carrying them, and the relative amount of resources devoted to the weapons varies from one system to another. In a study comparing the relative merits of shipboard weapons it is therefore desirable to pay particular attention to the lifetimes of the weapon versus its carrier, in this case the escort ship.

Certain parameters of this study have not yet been fixed (and may be treated as variables) but suppose the weapon and associated electronics are assumed to have a useful lifetime of 10 years, and the remainder of the ship consisting mainly of the hull and power plant are assumed to have a useful first-line life on the order of 25 years. The proportion of total cost devoted to the short-lived weapon system may influence the cost comparison significantly when appropriate recognition is given to the differing lifetimes. Hence, it is essential in this type of study to note such differences.

To illustrate the above point, suppose we have alternative escort ship designs whose weapons and electronics are expensive for one, and inexpensive for the other relative to the cost of the basic ship. An exaggerated hypothetical example is:

Alternative	A	B
Investment Cost, Dollars		
Basic Ship	100	10
Weapons and Elec	10	100
Operating Cost, Dollars Per Year	2	1
1. Annual cost for 25 years service and zero interest		
Basic Ship, 100/25 for A, 10/25 for B	4	0.4
Wpns & Elec, 10/10 for A, 100/10 for B	1	10.0
Operating Cost/Year	2	1.0
	7	11.4
2. Period outlay for <u>10 years</u>		
Basic Ship	100	10
Weapons and Elec	10	100
Operating cost, 10 years	20	10
	130	120

Comparing the alternatives on the basis of their annual costs shows alternative A to be less costly; when the outlays for a 10-year period are compared alternative B is shown to be less expensive. A similar comparison could be made between present cost and period outlay.

In the next section where alternative means for summarizing total systems costs are compared, either the present cost or the annual cost technique is used depending upon which represents the simpler set of calculations. These 2 methods are interchangeable in concept.

SOME IMPLICATIONS

As defined in the previous section, only 2 of the 5 summarizing techniques are simultaneously sensitive to differences in cash flow patterns, build-up costs and useful lifetime estimates. They are the present cost and annual cost techniques. For purposes of making comparisons, hypothetical examples are postulated, and their costs are summairzed in turn by each of the simpler techniques — 5-year system cost, period outlay, and net cost — and interest rates implied by their use are given.

Five-Year System Cost Versus Present/Annual Cost. The simplest technique and the one most commonly employed in connection with individual weapon systems analysis is the 5-year system cost. Niskanen gave the discount rate implications of its use in an address to the joint conference of CORS-ORSA, (reference (j)). He writes, "......this construct (meaning 5-year system cost) implies that interest rates of zero percent for systems with a useful life of 5 years, of 15 percent for systems with a 10-year life and of 20 percent for systems with an indefinite longer life are being used to discount future costs. An interest rate of around 15 percent, I believe, is appropriate for military and other government planning, as this rate is approximately equal to the marginal rate of return before taxes on capital in the private sector, but this or any other rate should not be used without some consideration or in a way which discriminates among systems with different useful lives. The 5-year system cost is a more-or-less accurate proxy for the present value of total weapon system costs discounted at 15 percent only for systems with a useful life of 10 years or longer."

Niskanen's statement referring to implied discount rates is apparently based on an analysis which assumes the research and development plus initial investment (non-recurring costs) occur now and the annual operating costs occur over the next 5 years. For example, suppose the non-recurring cost for a weapon is $100, and the annual operating cost is $20. The total cost over 10 years discounted at zero percent is $300, and the total 5-year-system cost is $200 (100 + 5 x 20). Assuming the system has a 10-year life, and applying a 15 percent discount rate, the present cost is about $200, or approximately equal to the 5-year system cost. If we assume that same system has a life of 20 years, and discount at 20 percent, the present cost is still about $200; and this appears to be the basis for Niskanen's statements. However, such a cost stream is not representative of the expenditure pattern required for the development, procurement, and operation of a typical weapon system.

A more realistic expenditure pattern is indicated in table II and figure 2. The initial investment funds are expended over a period of 7 years overlapping

the last 3 years of development effort, and the annual operating costs begin with the phase-in of the first operational system in the sixth year after initiation of system development.

TABLE II

HYPOTHETICAL WEAPON SYSTEM EXPENDITURES

Discount Rate	R&D Zero Percent	II Zero Percent	AO Zero Percent	Total Zero Percent	5 Percent	15 Percent
Year						
1	10			10	9.5	8.7
2	30			30	27.2	22.7
3	50			50	43.2	32.9
4	60			60	49.4	34.3
5	40	30		70	54.8	34.8
6	10	60	20	90	67.2	38.9
7	10	150	50	210	149.2	78.9
8		150	80	230	155.7	75.2
9		150	110	260	167.6	73.9
10		150	140	290	178.3	71.7
11		40	150	190	111.1	40.8
12			150	150	83.5	28.0
13			150	150	79.5	24.4
14			150	150	75.8	21.2
15			150	150	72.2	18.4
16			150	150	68.7	16.0
[illegible]			150	150	65.4	13.9
[illegible]			150	150	62.3	12.1
19			150	150	59.4	10.5
20			150	150	56.5	9.2
	210	730		2840	1636.5	666.5

Extracting from table II the costs which would normally be considered the 5-year cost estimate for a future weapon system, we add the R&D ($210) to initial investment ($730), and to this sum we add 5 years of level operating costs (5 x $150) and obtain $1,690. The discount rate implied by using the 5-year system cost as an estimate of the total cost of buying the system and operating it for 10 years after phase-in period is about 5 percent (i.e., $1636.5 versus $1690). The discount rate is applied to all costs including the phase-in costs which are excluded from the simple 5-year approach. The cost stream including build-up costs adds to about $670 when discounted at 15 percent, and the 5-year system cost is therefore not a good approximation if 15 percent is truly an appropriate rate for military planning. Assuming the operating life is 20 years beyond phase-in, the implied rate of interest is about 7 percent.

Selected for illustrative purposes is a non-recurring cost stream extending over a rather long period of time, and one which may not be typical. If one assumes foreshortened development and initial investment periods then the implied discount rate would be something greater than 5 percent.

Suppose, as an intermediate example, we assume relevant costs divide appropriately between non-recurring and recurring categories. Non-recurring costs are expended over a period of 2 years, and operation of the system begins at the end of the second year. Build-up costs, usually typical, are excluded to avoid their baising effect on this comparison. The cost stream is as follows: non-recurring costs are $400 now and $600 at the end of the first year, and the operating costs are $100 at the end of the second and each subsequent year. The 5-year system costs add to $1,500. Assuming a useful life of 5 years, a zero rate of interest is implied; 10 years implies a rate of about 9 percent and 20 years a rate of about 12 percent.

As another variant, let's examine the implications of a stream of uniform annual costs in which the non-recurring costs are sunk and therefore irrelevant. The stream comprises a series of uniform annual disbursements of $100. The implications of summarizing this pattern of costs using the 5-year approach are precisely the same as those referred to by Niskanen; that is, a zero interest rate is implied if the useful life is 5 years, 15 percent if 10 years, and 20 percent for an infinite life.

An ever-increasing cash flow pattern represents another interesting example. Suppose one estimates the operating and maintenance costs for a system will increase by a uniform amount each year; i.e., $100 for the first year, $110 for the second, $120 for the third, etc. Assuming the non-recurring costs are sunk, the 5-year system costs add to $600. If the useful life of the system is 10 years, an interest rate of about 18 percent is implied by the use of the 5-year system cost, and about 23 percent if its life is 20 years.

It is apparent that the implications of selecting the 5-year system cost technique as an appropriate summary device vary quite widely depending upon the shape of the cash flow pattern. In the few examples above, implied discount rates vary from about 5 to 18 percent for systems expected to have a useful lifetime of 10 years, and from 7 to 23 percent for those lasting 20 years.

<u>Period Outlay Versus Present/Annual Cost.</u> Recall that period outlay includes build-up costs, and that is the principle difference between it and the 5-year system cost technique. In table II, the period outlay including 5 years of level operations adds to $2090. If that system has an estimated useful life of only 5 years then the rate of interest implied by the use of the period outlay summarizing technique is zero percent. If, on the other hand, the system has a useful operational life of 10 years and one includes period outlay for operating it only 5 years, the implied rate of interest is about 3 percent, and about 5 percent if the useful operational period is 20 years. Lower rates are implied by the period outlay technique than by the 5-year system cost merely because build-up costs are an integral part of the former.

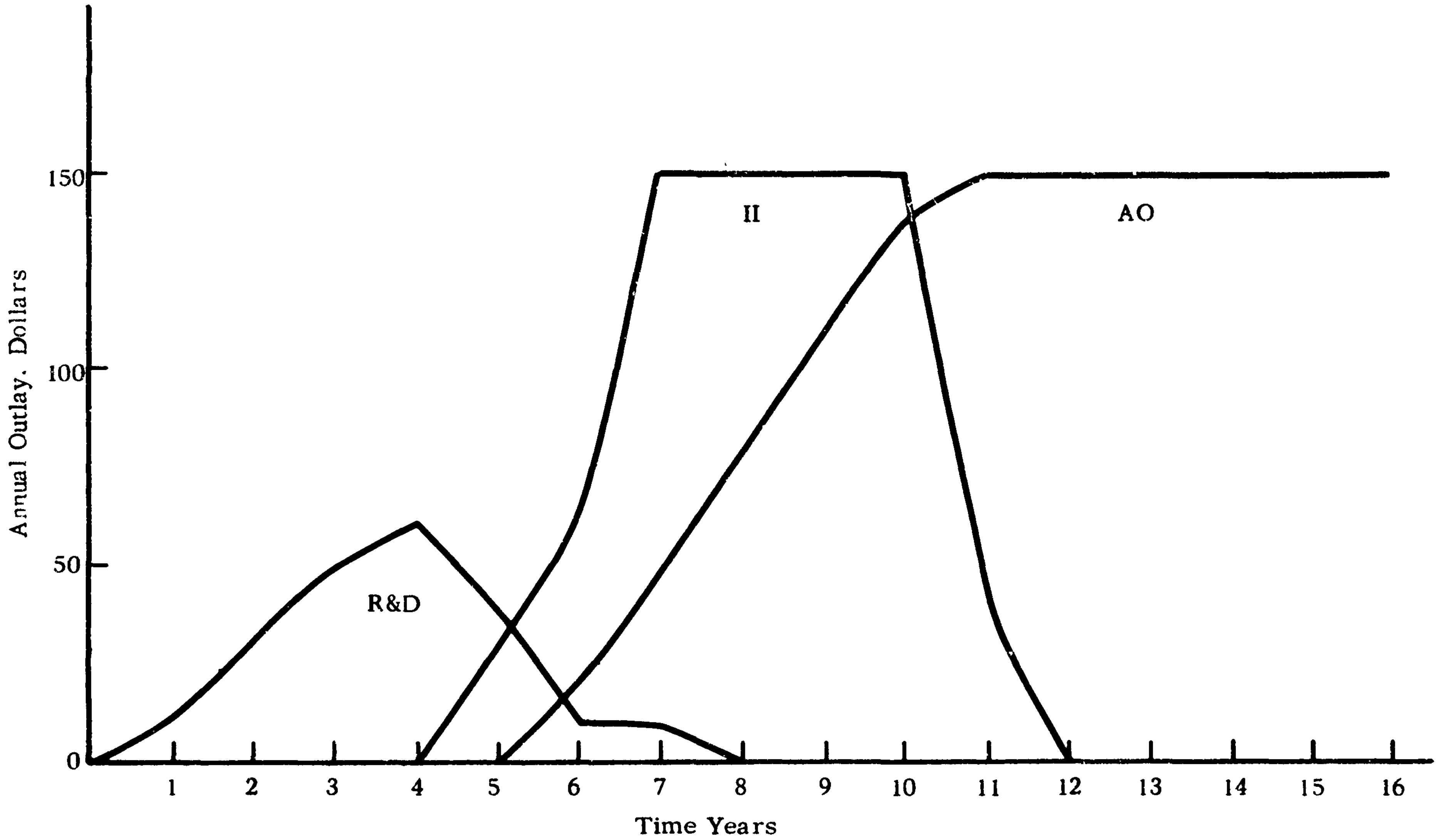


FIG. 2: HYPOTHETICAL EXPENDITURE PATTERN

The implications cited for the 5-year technique in the previous section apply to period outlay for all those examples in which build-up costs are insignificant. This of course assumes that consideration given to the listing of assets still in service as of the study cut-off date is not quantified.

Because build-up costs usually are incurred relatively early during the time period under study, their influence on implied discount rates is worth noting. For systems whose cost streams are exemplified by the pattern in figure 2, the following comparison may be made:

	Interest Rate Implications	
Expected Useful Life	10 Years	20 Years
Period Outlay, 5 Years	3%	5%
Five-Year System Cost	5%	7%

Net Cost Versus Present/Annual Cost. The unique characteristics of the net cost technique apply primarily to those cases in which the selected time horizon is a date short of the useful lifetimes (assuming zero salvage value) of at least one of the alternatives, and in which capital assets must be developed and/or procured. For example, if we are considering the replacement of an existing system, and the cost of retaining that system is its operating cost only, and at the end of its life it will be disposed of at a cost equal to its scrap value (i.e., zero salvage value), then there is no need for the employment of the net cost technique.* If on the other hand we are considering the development and procurement of a new system, and our study cut-off date falls short of the estimated useful lifetime of the new system, some recognition should usually be given to the value remaining. Rates of interest implied by the calculation of remaining values in a case similar to the latter are examined; the hypothetical set of costs in table II serves as the example.

It is not obvious just what costs in that example should be treated as depreciable. Should the production costs of capital assets included in the initial investment category represent the only costs to be amortized? Or should depreciable costs include all investment costs? Should they include R&D costs as well? How about build-up costs? Of course, we must remember that the original cost of an asset, or system, is sunk and therefore irrelevant to the estimation of that asset's value at some future date. (See the previous section, "Remaining Value".) But as a practical matter we sometimes rely upon the accountant's methods for amortizing original cost, whatever that may be, to make estimates of remaining values.

*Unless somehow we want to treat the remaining value of such things as our recurring investment in education and training of personnel, etc.

For purposes of comparison, R&D and initial investment costs are considered to represent the original cost of the system. Recurring costs including those required to phase-in the system are not considered a part of original cost. The net cost of acquiring the hypothetical system and of operating it for 5 years at a uniform rate is calculated in each of the 4 ways described in the previous section on remaining value, i.e., straight-line, double declining balance, sum-of-the-years digits, and the 10 percent sinking fund methods.

Assuming the useful lifetime of the system is just 5 years operating at a level force size, all methods imply the use of a zero percent rate of interest except declining balance; it implies slightly more than zero percent because the declining balance method does not fully amortize original cost. If, on the other hand, we assume the useful operating life is 10 years, the net cost for 5 years implies an interest rate of about 4 percent for both the declining balance and sum-of-the-years digits methods; for the straight-line method a rate of about 5 percent is implied, and about 6 percent for the sinking fund method. For a 20 year assumed lifetime for the system, the implied rates of interest are about 8, 7, and 10 percent, respectively.

An interesting comparison may be made for the example which treats all non-recurring costs as a present outlay, and operating costs as uniform annual outlays beginning at the end of the first year. Suppose, for example, the non-recurring cost is $1,000 and the annual operating cost is $100. Assuming the system has a useful operational life of 10 years, the net cost for 5 years based on straight-line amortization of non-recurring cost is $1,000; i.e., one half of the non-recurring cost plus 5 years operating cost. Implicit in the use of net cost in this particular example is an infinite rate of interest. That is, the present cost of the non-recurring amount is $1,000; all recurring costs must be discounted to zero in order to yield a present cost for the stream equal to $1,000.

Assuming the system has a lifetime of 20 years, the net cost for 5 years is $750, an amount less than the present cost of the stream discounted at an infinite rate of interest. The net cost for 5 years using the declining balance and sum-of-the-years digits methods imply rates of between 40 and 50 percent when the system is assumed to have a useful life of 10 years. The net cost for 5 years found by all 4 methods of depreciation is an amount less than the non-recurring cost, and less than the present cost of the cost stream when discounted at an infinite rate, if the system is assumed to have a life of 20 years.

Several cost streams which differ in shape are postulated in appendix B. Each stream is summairzed by the techniques defined and described in this document, and the results are briefly compared.

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APPENDIX A

TABLE A-I

INTEREST TABLE, SINGLE PAYMENT COMPOUND AMOUNT FACTORS $(1 + i)^n$

	Discount Rate									
n	3%	4%	5%	6%	8%	10%	12%	15%	20%	25%
1	1.030	1.040	1.050	1.060	1.080	1.100	1.120	1.150	1.200	1.25
2	1.061	1.082	1.103	1.124	1.166	1.210	1.254	1.322	1.440	1.56
3	1.093	1.125	1.158	1.191	1.260	1.331	1.405	1.521	1.728	1.95
4	1.126	1.170	1.216	1.262	1.360	1.464	1.574	1.749	2.074	2.45
5	1.159	1.217	1.276	1.338	1.469	1.611	1.762	2.011	2.488	3.06
6	1.194	1.265	1.340	1.419	1.587	1.772	1.974	2.313	2.986	3.82
7	1.230	1.316	1.407	1.504	1.714	1.949	2.211	2.660	3.583	4.76
8	1.267	1.369	1.477	1.594	1.851	2.144	2.476	3.059	4.300	5.96
9	1.305	1.423	1.551	1.689	1.999	2.358	2.773	3.513	5.160	7.46
10	1.344	1.480	1.629	1.791	2.159	2.594	3.106	4.046	6.192	9.31
11	1.384	1.539	1.710	1.898	2.332	2.853	3.479	4.652	7.430	11.64
12	1.426	1.601	1.796	2.012	2.518	3.138	3.896	5.350	[illegible]	14.55
13	1.469	1.665	1.886	2.133	2.720	3.452	4.363	6.153	[illegible]	18.18
14	1.513	1.732	1.980	2.261	2.937	3.797	4.887	7.076	[illegible]	22.72
15	1.558	1.801	2.079	2.397	3.172	4.177	5.474	8.137	15.407	28.40
16	1.605	1.873	2.183	2.540	3.426	4.595	6.130	9.358	18.488	35.58
17	1.653	1.948	2.292	2.693	3.700	5.054	6.866	10.761	22.186	44.44
18	1.702	2.026	2.407	2.854	3.996	5.560	7.690	12.375	26.623	55.55
19	1.754	2.107	2.527	3.026	4.316	6.116	8.613	14.232	31.948	69.44
20	1.806	2.191	2.653	3.207	4.661	6.727	9.646	16.367	38.338	86.95
21	1.860	2.279	2.786	3.400	5.034	7.400	10.804	18.821	46.005	108.69
22	1.916	2.370	2.925	3.604	5.437	8.140	12.100	21.645	55.206	135.13
23	1.974	2.465	3.072	3.820	5.871	8.954	13.552	24.891	66.247	169.49
24	2.033	2.563	3.225	4.049	6.341	9.850	15.179	28.625	79.497	212.76
25	2.094	2.666	3.386	4.292	6.848	10.835	17.000	32.919	95.396	263.15
26	2.157	2.772	3.556	4.549	7.396	11.918	19.040	37.857	114.475	333.33
27	2.221	2.883	3.733	4.822	7.988	13.110	21.325	43.535	137.370	416.66
28	2.288	2.999	3.920	5.112	8.627	14.421	23.884	50.065	164.845	526.31
29	2.357	3.119	4.116	5.418	9.317	15.863	26.750	57.575	197.813	666.66
30	2.427	3.243	4.322	5.743	10.063	17.449	29.960	66.212	237.376	833.33

TABLE A-III

DECLINING BALANCE FACTORS, $(1 - i)^n$

Declining Balance Depreciation Rate, i

n	3.33	4.00	5.00	6.00	6.67	7.50
1	0.9667	0.9600	0.9500	0.9400	0.9333	0.9250
2	0.9345	0.9216	0.9025	0.8836	0.8710	0.8556
3	0.9034	0.8847	0.8574	0.8306	0.8130	0.7915
4	0.8733	0.8493	0.8145	0.7808	0.7587	0.7321
5	0.8442	0.8154	0.7738	0.7339	0.7081	0.6772
6	0.8161	0.7828	0.7351	0.6899	0.6609	0.6264
7	0.7889	0.7515	0.6983	0.6485	0.6168	0.5794
8	0.7627	0.7214	0.6634	0.6096	0.5757	0.5360
9	0.7373	0.6925	0.6303	0.5730	0.5373	0.4958
10	0.7127	0.6648	0.5988	0.5386	0.5015	0.4586
11	0.6890	0.6383	0.5688	0.5063	0.4680	0.4242
12	0.6661	0.6127	0.5404	0.4759	0.4368	0.3924
13	0.6439	0.5882	0.5134	0.4474	0.4077	0.3630
14	0.6224	0.5647	0.4878	0.4206	0.3305	0.3358
15	0.6017	0.5421	0.4633	0.3953	0.3551	0.3106
16	0.5817	0.5204	0.4402	0.3716	0.3314	0.2873
17	0.5623	0.4996	0.4181	0.3493	0.3093	0.2658
18	0.5436	0.4796	0.3972	0.3283	0.2887	0.2458
19	0.5255	0.4604	0.3774	0.3087	0.2694	0.2274
20	0.5080	0.4420	0.3585	0.2901	0.2515	0.2103
21	0.4911	0.4243	0.3406	0.2727	0.2347	0.1946
22	0.4747	0.4074	0.3236	0.2564	0.2190	0.1800
23	0.4589	0.3911	0.3074	0.2410	0.2044	0.1665
24	0.4436	0.3754	0.2920	0.2265	0.1908	0.1540
25	0.4289	0.3604	0.2774	0.2129	0.1781	0.1425
26	0.4146					
27	0.4008					
28	0.3874					
29	0.3745					

TABLE A-II

INTEREST TABLE, SINGLE PAYMENT PRESENT COST FACTOR $(1 + i)^{-n}$

Discount Rate

n	3%	4%	5%	6%	8%	10%	12%	15%	20%	25%
1	0.9709	0.9615	0.9524	0.9434	0.9259	0.9091	0.8929	0.8696	0.8333	0.8000
2	0.9426	0.9246	0.9070	0.8900	0.8573	0.8264	0.7972	0.7561	0.6944	0.6400
3	0.9151	0.8890	0.8638	0.8396	0.7938	0.7513	0.7118	0.6575	0.5787	0.5120
4	0.8885	0.8548	0.8227	0.7921	0.7350	0.6830	0.6355	0.5718	0.4823	0.4096
5	0.8626	0.8219	0.7835	0.7473	0.6806	0.6209	0.5674	0.4972	0.4019	0.3277
6	0.8375	0.7903	0.7462	0.7050	0.6302	0.5645	0.5066	0.4323	0.3349	0.2621
7	0.8131	0.7599	0.7107	0.6651	0.5835	0.5132	0.4523	0.3759	0.2791	0.2097
8	0.7894	0.7307	0.6768	0.6274	0.5403	0.4665	0.4039	0.3269	0.2326	0.1678
9	0.7664	0.7026	0.6446	0.5919	0.5002	0.4241	0.3606	0.2843	0.1938	0.1342
10	0.7441	0.6756	0.6139	0.5584	0.4632	0.3855	0.3220	0.2472	0.1615	0.1074
11	0.7224	0.6496	0.5847	0.5268	0.4289	0.3505	0.2875	0.2149	0.1346	0.0859
12	0.7014	0.6246	0.5568	0.4970	0.3971	0.3186	0.2567	0.1869	0.1122	0.0687
13	0.6810	0.6006	0.5303	0.4688	0.3677	0.2897	0.2292	0.1625	0.0935	0.0550
14	0.6611	0.5775	0.5051	0.4423	0.3405	0.2633	0.2046	0.1413	0.0779	0.0440
15	0.6419	0.5553	0.4810	0.4173	0.3152	0.2394	0.1827	0.12[illegible]	0.0649	0.0352
16	0.6232	0.5339	0.4581	0.3936	0.2919	0.2176	0.1631	0.1069	0.0541	0.0281
17	0.6050	0.5134	0.4363	0.3714	0.2703	0.1978	0.1456	0.0929	0.0451	0.0225
18	0.5874	0.4936	0.4155	0.3503	0.2502	0.1799	0.1300	0.0808	0.0376	0.0180
19	0.5703	0.4746	0.3957	0.3305	0.2317	0.1635	0.1161	0.0703	0.0313	0.0144
20	0.5537	0.4564	0.3769	0.3118	0.2145	0.1486	0.1037	0.0611	0.0261	0.0115
21	0.5375	0.4388	0.3589	0.2942	0.1987	0.1351	0.0926	0.0531	0.0217	0.0092
22	0.5219	0.4220	0.3418	0.2775	0.1839	0.1228	0.0826	0.0462	0.0181	0.0074
23	0.5067	0.4057	0.3256	0.2618	0.1703	0.1117	0.0738	0.0402	0.0151	0.0059
24	0.4919	0.3901	0.3101	0.2470	0.1577	0.1015	0.0659	0.0349	0.0126	0.0047
25	0.4776	0.3751	0.2953	0.2330	0.1460	0.0923	0.0588	0.0304	0.0105	0.0038
26	0.4637	0.3607	0.2812	0.2198	0.1352	0.0839	0.0525	0.0264	0.0087	0.0030
27	0.4502	0.3468	0.2678	0.2074	0.1252	0.0763	0.0469	0.0230	0.0073	0.0024
28	0.4371	0.3335	0.2551	0.1956	0.1159	0.0693	0.0419	0.0200	0.0061	0.0019
29	0.4243	0.3207	0.2429	0.1845	0.1073	0.0630	0.0374	0.0174	0.0051	0.0015
30	0.4120	0.3083	0.2314	0.1741	0.0994	0.0573	0.0334	0.0151	0.0042	0.0012

APPENDIX B

COMPARISON OF ALTERNATIVE COST STREAMS

Comparison of Alternative Cost Streams. Four separate cost streams are postulated to describe hypothetical defense systems, and their costs are calculated by the techniques defined and described in this document. The cost streams are selected to span a range of patterns and yet bear some resemblance to reality with the possible exception of the first alternative.

Alternative A is represented by a cost pattern requiring a cost now of $1,000 and recurring annual costs of $100. While it is difficult to conceive of a major defense system requiring the expenditure of funds in such a manner, this particular pattern is selected because it resembles the way we sometimes lay out 5-year system costs. That is, 5-year system costs are not generally time-phased, and crude approximations to time-phasing usually follow the pattern described for alternative A.

The cost stream for alternative B is supposed to represent an existing system whose annual operating costs are expected to increase by a uniform amount to extend its operational life. Alternatives C and D have cost patterns similar to each other; acquisition costs for C are $1,000 and it is expected to have a life of 10 years at level operations, and D is estimated to cost twice as much initially and last twice as long.

Several interesting points are indicated by the comparison of system costs calculated using the various techniques described in this document. Probably one of the most significant points to bring out is that one should not compare all 4 alternatives, one with the others. They do not provide a service over the same period of time; that is, alternatives A and B become operational in the first year, but C and D do not become fully operational until the fourth year.

For example, if one desired to compare the system costs of alternative B with C, the alternatives would probably be described somewhat as follows:

Alternative B: continue to operate existing system for the next 10 years, expecting to increase the operating expense each year.

Alternative C: continue to operate existing system while proceeding with the acquisition of a new system expected to become partially operational in the second year and fully operational in the fourth. Phase the existing system out as the new one is phased in. The two cost streams may reduce to:

TABLE A-III (Cont'd)

	Declining Balance Depreciation Rate, i						
	8.00	10.00	13.33	15.00	20.00	30.00	40.00
1	0.9200	0.9000	0.8667	0.8500	0.8000	0.7000	0.6000
2	0.8464	0.8100	0.7512	0.7225	0.6400	0.4900	0.3600
3	0.7787	0.7290	0.6510	0.6141	0.5120	0.3430	0.2160
4	0.7164	0.6561	0.5643	0.5220	0.4096	0.2401	0.1296
5	0.6591	0.5905	0.4891	0.4437	0.3277	0.1681	0.0778
6	0.6064	0.5315	0.4239	0.3772	0.2622		
7	0.5579	0.4783	0.3674	0.3206	0.2097		
8	0.5132	0.4305	0.3184	0.2725	0.1678		
9	0.4722	0.3874	0.2760	0.2316	0.1342		
10	0.4344	0.3487	0.2392	0.1969	0.1074		
11	0.3997	0.3138	0.2073				
12	0.3677	0.2825	0.1797				
13	0.3383	0.2542	0.1557				
14	0.3112	0.2288	0.1350				
15	0.2863	0.2059	0.1170				
16	0.2634	0.1853					
17	0.2424	0.1668					
18	0.2230	0.1501					
19	0.2051	0.1351					
20	0.1887	0.1216					
21	0.1736						
22	0.1598						
23	0.1470						
24	0.1352						
25	0.1244						

TABLE B-I

ALTERNATIVE COST STREAMS SUMMARIZED

Alternative	A		B		C		D	
Non-Recurring/Recurring	N	R	N	R	N	R	N	R
End-of-Year								
0	1,000		0		100		200	
1		100		120	300		600	
2		100		140	400	50	800	50
3		100		160	200	80	400	80
4		100		180		100		100
.	(and so on thru year 10)		(increasing by $20 each year)		(and so on thru yr. 13)		(and so on thru year 23)	
.								
Estimated Operational Life, Yrs.		10*	Indefinite			10*		20*
Total System Cost, Dollars								
1. Five-Year System Cost		1,500		800		1,500		2,500
2. Total Outlay, 5 years		1,500		800		1,630		2,630
10 years		2,000		2,100		1,830		2,830
3. Net Cost, 5 years								
a) Straight-Line		1,000		800		1,130		1,130
b) Double Declining Balance		1,172		800		1,302		1,449
c) Sum-of-Years Digits		1,227		800		1,357		1,487
d) 10% Sinking Fund		883		800		1,013		,844
4. Present Cost, 5%, 10 years		1,772		1,560		1,808		2,624
5%, 20 years		2,861		3,646		2,918**		3,034
10%, 10 years		1,614		1,196		1,459		2,270
10%, 20 years		2,236		2,130		2,021**		2,448
5. Annual Cost, 5%, 10 years		230		202		192		279
5%, 20 years		230		278		216**		225
10%, 10 years		263		195		205		320
10%, 20 years		263		250		228**		276

*Lifetimes given in years of level operations, except for alternative B.

**Assume: development of replacement system begins end-of-year 10 and original cost history is repeated, requiring a total of 23 years.

Alternative		B	C		
System		Existing	Existing		New
Recurring/Non-Recurring		R	R	N	R
Year	0	-0-		100	
	1	120	120	300	
	2	140	70	400	50
	3	160	32	200	80
	4	180	-0-		100
	.	.	.		.
	.	.	.		.
	.	.	.		.
	10	300	-0-		100

One may compare directly the costs of alternatives A and B, and of C and D. Between the first 2 alternatives, B appears to be the less expensive for all techniques except the period outlay for 10 years and the present cost for 20 years at 5 percent. Because alternative B is defined as an existing system whose life may be extended by increasing the operating expense, its estimated lifetime is considered indefinite. The present cost comparison at 5 percent favors B if we examine the next 10 years, but favors A when we examine 20 years. Alternative B reaches a very high rate of operating costs in the second 10-year period, and A is assumed to repeat its cost history. It is very likely that a decision maker would decide in favor of B now if the option to re-examine the case is left open. In such a situation, the display of either the period outlay for 10 years or the present cost for 20 years and 5 percent interest to the exclusion of other summaries may be misleading.

The display of a 5-year system cost which shows a marked advantage for B is misleading in this case only in magnitude, not in direction. The advantage indicated for B is reduced by a comparison of net costs for 5 years, and one of these techniques may be more appropriate than the 5-year method, especially if we are limiting our examination to 5 years.

In the comparison of alternatives C and D, C is favored by all techniques except net cost for 5 years using the sinking fund method of depreciation. Net cost for 5 years using the straight-line method shows the two alternatives to be equally expensive, and no choice can be made on the basis of this summarizing technique. However, the fact that a choice can be made on the basis of a particular technique is of course insufficient reason for its use.

NONE

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13. ABSTRACT

Some techniques used to summarize total costs employed in systems analyses are classified, described, and compared. Their respective advantages and disadvantages are given, and some implications of each are brought out.

Five cost-summarizing techniques are selected and distinctions between them are based on common usage. The procedures are termed:

- Five-Year System Cost
- Period Outlay
- Net Cost
- Present Cost
- Annual Cost

Necessary to their discussion is an understanding of the major types and general content of defense system cost analyses, the concept of remaining value, and the principle that money has time value. A brief section on each of these subjects with appropriate references precedes the discussion of the methods for summarizing costs.

NONE
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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Net Cost						
Present Cost						
Annual Cost						
Period Outlay						
Five-Year System Cost						

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